IR057

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Mr. David Bird
State of Utah Department of Environmental Quality
Division of Environmental Response and Remediation
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Subject: Transmittal of RADON Modeling Results on Cover Performance Using Actual Soil Property Data

Dear Mr. Mushovic and Mr. Bird:

Enclosed for your information are the results of modeling radon emissions from the Monticello Repository cover using actual soil property data. Samples were collected from various sources that could be used to construct the MVP 3-foot layer and stockpiles that will be used to construct the radon barrier.

If you have any questions, please do not hesitate to contact me at (970) 248-6091.

Sincerely,

Raymond M. Plieness
Project Manager

Enclosure

cc w/enclosure:
J. Berwick, DOE-GJO
Project File: MRAP 4.1.3 (J. Glasgow)

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Addendum to Calc. No. E0269801:
Radon Barrier Thickness Estimation Using RADON Code
March 31, 1999

Problem Statement:

Use the NRC program, RADON (U.S. Nuclear Regulatory Commission 1989), to evaluate radon flux for the following three scenarios:

1. Estimate radon flux at the top of the radon barrier, and at the surface of the repository cover, in pCi m^{-2} s^{-1}, assuming a layer of residual radioactive material (RRM) will be placed last in the repository, immediately below the radon barrier, given the following assumptions.

   - The RRM layer will consist of one or more of the following materials:

     Haul road material—the surface 30 cm of the haul road that became contaminated during the hauling of tailings to the repository.

     Acid Pile Drying Table, Non-Tailings Material—Substrate remaining, after removal of tailings, that is contaminated with > 15 pCi/g radium-226; MPP material; and creek channel material.

     Residual vadose zone (RVZ) soils—contaminated native soils between tailings and ground water. These materials, contaminated with metals, remained after the removal of tailings and "base of tailings" soil that had > 15 pCi/g radium-226.

     Interim stockpile—vicinity property soils temporarily stockpiled before hauling to the repository.

   - The RRM layer will be between 30 and 90 cm thick.

   - The lower 45 cm of the radon barrier (Lower Radon Barrier material) will consist of Type D material that was stockpiled during excavation of the repository. This Lower Radon Barrier material must have greater than 85% passing a No. 4 sieve and 50% less than a No. 200 sieve.

   - The upper 15 cm of the radon barrier (Upper Radon Barrier material) will consist of Type D material processed from the common stockpile. In addition to the above criteria for Lower Radon Barrier material, 100% of this processed must be less than 12.7 mm (0.5 in.).

- Combinations of the following different repository and cover materials—different treatments or design configurations—are possible.

  RRM Material Type: haul road material, acid pile drying table non-tailings material, RVZ soils, or interim stockpile material.

  RRM Layer Thickness: 90 cm and 30 cm.

  Radon Barrier: 45 cm of Lower Radon Barrier material with 15 cm of Upper Radon Barrier material placed above it.

  "Sponge" Layer: Rn flux is calculated both at the top of the radon barrier and at the surface of an overlying 132 cm layer of Type E soil. The total thickness of earthen material overlying the capillary break is actually 168 cm (66 in.). However, rock in the Type F animal intrusion layer and in the gravel admixture layer provides no water storage. The thickness of these layers combined is 51 cm (20 in.). Given the volume of rock in these layers, 132 cm (52 in.) is considered to be a conservative estimate of the effective storage thickness of the sponge layer.

2. Estimate radon flux at the top of the radon barrier, and at the surface of the repository cover, in pCi m^{-2} s^{-1}, assuming no RRM layer will be placed above the tailings. Evaluate the sensitivity of radon flux to the compaction (bulk density) of the radon barrier.

3. Estimate the maximum radium level that can be allowed in a 90 cm RRM layer without exceeding the 20 pCi m^{-2} s^{-1} flux standard at the surface of the radon barrier. Use conservative proctor test data for the radon barrier bulk density.

Unless stated otherwise, all input parameter assumptions are consistent with the original Calc. No. E0269801.

Method of Solution:

Calculate the radon barrier thickness using the NRC program, RADON (U.S. Nuclear Regulatory Commission 1989).

Assumptions:

- The different types of tailings materials (slimes, sands, mixed slimes and sands), with varying radium activity levels, will be combined during placement in the repository.

- The design approach demonstrates compliance with the 20 pCi m^{-2} s^{-1} radon flux standard at the top surface of the radon barrier. Overlying soil layers are expected to provide considerable radon attenuation, therefore, radon flux is also calculated at the surface of the cover.

- Mean and standard error of the mean values for each RADON input parameter, for unbiased estimates of obtainable material properties, are important design statistics. Uncertainty in cover thickness estimates can be evaluated by inputting the mean ± standard error of the mean for input parameters. Using these values, the uncertainty in cover thickness due to uncertainty in all obtainable material properties should be less than one foot (U.S. Department of Energy, 1989).

- The HDPE layer is excluded from the RADON flux calculations. The HDPE layer is expected to greatly limit gas diffusion (Ramachandran et al., 1987), but for our purposes, it is considered to be an additional safety factor.

- The sand capillary barrier layer is excluded from the RADON flux calculation. Moisture retained in the sand layer is considered to be an additional safety factor.

- Seasonal accumulation of snow, which provides considerable radon attenuation (U.S. Department of Energy, 1989), is excluded from the RADON flux calculation. Snow is considered to be an additional safety factor

RADON input parameter assumptions:

Tailings Layer Thickness Because a tailings layer ≥ 500 cm thick represents an equivalent infinitely thick tailings source of radon (U.S. Nuclear Regulatory Commission, 1989), and the tailings layer in the Monticello repository will be at least 500 cm, a precise estimate of the tailings layer thickness is not needed.

Specific Gravity A value of 2.65 for specific gravity (the density of quartz), used by the RADON program to calculate porosity of all layers, is conservative.

Bulk Density Bulk density (dry mass), or maximum dry density, determined from laboratory proctor curves for the various tailings and soil materials, provides an adequate representation of layer and lift compaction during construction of the repository.

Porosity The RADON program option for calculating material porosity (n_m) based on material bulk density (ρ_m), the mass density of water (ρ_w = 1.0), and specific gravity (G = 2.65), provides conservative estimates.

$$n_m = 1 - \rho_m/G\rho_w$$

Long-Term Average Moisture; Cover Soil moisture values from the cover material borrow site are appropriate input for long-term moisture if samples are obtained from depths greater than 120 cm (below the depth of high seasonal variability attributable to evapotranspiration), and above the water table (U.S. Nuclear Regulatory Commission, 1989).

Long-Term Average Moisture; Tailings Moisture content calculated by unsaturated flow models is adequate for the tailings provided that the models are fully documented and validated for the range of possible site conditions (U.S. Nuclear Regulatory Commission, 1989).

Tailings Radium Activity The volume-weighted mean value of radium activity (mean plus standard error of the mean) measured for each tailings material type (slimes, sands, mixed slimes/sands) and pile (East, Carbonate, Acid, and Vanadium) is an appropriate estimate of tailings radium activity in the repository, as long as sampling is unbiased (U.S. Department of Energy, 1989).

Radium Activity of Residual Radioactive Materials The mean value of radium activity (mean plus standard error of the mean) measured in RRM is an appropriate estimate of radium activity for RRM in the repository, as long as sampling is unbiased.

Radium Activity in the Radon Barrier A value of zero for radium activity in the radon barrier is appropriate provided that borrow materials are not associated with radium-enriched materials (U.S. Nuclear Regulatory Commission, 1989).

Radon Emanation Fraction The volume-weighted mean value of radon emanation fraction (mean plus standard error of the mean) measured for each tailings material type (slimes, sands, mixed slimes/sands) and pile (East, Carbonate, Acid, and Vanadium) is an appropriate estimate of tailings radon emanation fraction in the repository, as long as sampling is unbiased. The mean values of radon emanation fraction (mean plus standard error of the mean) measured for RRM is also appropriate.

Radon Diffusion Coefficient The NRC (U.S. Nuclear Regulatory Commission, 1989) default calculation for radon diffusion coefficients in the tailings, peripheral property materials, and cover materials is conservative.

Ambient Radon Above Top Layer A value of zero for the radon concentration above the soil/air interface is conservative (U.S. Nuclear Regulatory Commission, 1989).

Lower Boundary Radon Flux For repositories with thick tailings layers, radon flux into the layers beneath the tailings can be considered to be zero (U.S. Nuclear Regulatory Commission, 1989).

Numerical Precision A value of 0.001 pCi m^{-2} s^{-1} is an acceptable level of numerical precision in the radon surface flux computation.

Calculation:

Input parameter values used to calculate radon flux for the different cover scenarios are given in Table 1. Footnotes for data sources follow the table. Input values are mean and mean ± the standard error of the mean (S.E.) unless stated otherwise. RADON model runs are attached.

Table 1. Input values and data sources for RADON model calculation of radon flux.

Input Parameter	Tailings	Acid Pile Drying Table Non-tailings Material	RVZ Material	Interim Stockpile	Haul Road Material	Radon Barrier (lower 45 cm)	Radon Barrier (upper 15 cm)	Sponge Layer
Layer Thickness (cm)	1500 cm	90 cm	90 cm	90 or 30 cm	90 cm	45 cm	15 cm	132 cm
Source:	Design Thickness	Design Thickness	Design Thickness	Design Thickness	Design Thickness	Design Thickness	Design Thickness	Design Thickness
Bulk Density (g/cm^3)	$\bar{x}$ = 1.52; S.E. = 0.02	$\bar{x}$ = 1.68; S.E. = 0.05	$\bar{x}$ = 1.56; S.E. = 0.06	$\bar{x}$ = 1.52; S.E. = 0.01	$\bar{x}$ = 1.82; S.E. = 0.01	$\bar{x}$ = 1.80 or 1.74 S.E. = 0.02	$\bar{x}$ = 1.81 or 1.74 S.E. = 0.02	1.45
Source:	(1)	(2)	(2)	(2)	(2)	(3, 4)	(3, 4)	(5)
Porosity (fractional)	Calculated by RADON	Calculated by RADON	Calculated by RADON	Calculated by RADON	Calculated by RADON	Calculated by RADON	Calculated by RADON	Calculated by RADON
Water Content (% dry-wt. basis)	13.1	13.1	13.1	13.1	13.1	$\bar{x}$ = 15.8; S.E. = 0.6	$\bar{x}$ = 15.8; S.E. = 0.6	$\bar{x}$ = 12.4
Source:	(6)	(6)	(6)	(6)	(6)	(7)	(7)	(8)
Ra-226 Activity (pCi/g)	$\bar{x}$ = 782.7; S.E. = 54.2	$\bar{x}$ = 54.9; S.E. = 24.7	$\bar{x}$ = 4.6; S.E. = 2.2	$\bar{x}$ = 66.4; S.E. = 24.3	$\bar{x}$ = 35.6; S.E. = 10.8	0	0	0
Source:	(9)	(2)	(2)	(2)	(2)			
Rn Emanating Fraction	$\bar{x}$ = 0.33; S.E. = 0.02	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Source:	(10)	RADON default value.	RADON default value.	RADON default value.	RADON default value.	RADON default value.	RADON default value.	RADON default value.
Rn Diffusion Coefficient ($cm^2 s^{-1}$)	Calculated by RADON	Calculated by RADON	Calculated by RADON	Calculated by RADON	Calculated by RADON	Calculated by RADON	Calculated by RADON	Calculated by RADON

Data Source Footnotes:

(1) Value is 90% of the maximum dry density from Calc. E0268300 (n = 31).

(2) Table 2. Values are 90% maximum dry density (mean and S.E.), rock %, optimum water content, and radium concentration data the Subcontractor provided from field sampling of RRM materials.

Material Type	Sample Number and Classification	Rock (%)	Maximum Dry Density (pcf)	90% MDD (g cm^{-3})	Optimum H2O Content (%)	Radium Conc. (pCi/g)
Acid pile drying table non-tailings material	xcon45 - brown shaley clay	3.8% > #4 sieve	110.0	1.60	16.9	61.7
	xcon47 - drk brn silty sand w/ gravel	8.3% > 3/8"	114.1	1.66	12.0	94.0
	xcon50 - drk brn silty sand w/ gravel	10.8% > 3/4"	121.9	1.78	10.9	9.1
	mean	7.6	115.3	1.68	13.3	54.9
	S.E. of the mean	2.0	3.5	0.05	1.8	24.7
RVZ	xcon46 - drk brn silty clay	3.2% > #4 sieve	100.9	1.47	20.7	2.2
	xcon48 - lt brn sandy silty clay	3.0% > #4 sieve	97.2	1.42	21.3	1.6
	xcon49 - drk brn silty sand w/ gravel	8.4% > 3/8"	115.1	1.68	14.1	15.7
	xcon51 - drk brn silty sand w/ gravel	27.8% > 3/4"	122.9	1.79	12.0	2.7
	xcon116 - tan sandy silty clay	4.0% > #4 sieve	103.4	1.51	19.8	1.9
	xcon117 - lt brn sandy silty clay	5.0% > #4 sieve	102.7	1.50	19.4	3.2
	mean	8.6	107.0	1.56	17.9	4.6
	S.E. of the mean	3.9	4.0	0.06	1.6	2.2
Interim stockpile	xcon52 - drk brn silty clay	3.5% > #4 sieve	104.7	1.53	20.4	138.5
	xcon53 - lt brn sandy silty clay	4.0% > #4 sieve	102.5	1.49	18.9	35.5
	xcon54 - lt brn sandy silty clay	3.5% > #4 sieve	106.1	1.55	18.0	51.2
	xcon55 - drk brn silty clay w/ gravel	3.5% > #4 sieve	104.4	1.52	18.9	40.4
	mean	3.6	104.4	1.52	19.1	66.4
	S.E. of the mean	0.1	0.7	0.01	0.5	24.3
Haul road	xcon784 - lt brn silty sand w/ gravel	15% > 3/8"	123.5	1.80	11.0	51.9
	xcon785 - drk brn silty sand w/ gravel	21.8% > 3/4"	125.3	1.83	11.4	37.3
	xcon786 - med brn silty sand w/ gravel	5.5% > 3/4"	126.4	1.84	10.5	48.7
	xcon787 - med brn silty sand w/ gravel	15.2% > 3/4"	124.6	1.82	10.1	4.6
	mean	14.4	125.0	1.82	10.8	35.6
	S.E. of the mean	3.4	0.6	0.01	0.3	10.8

(3) Table 3. Maximum dry density (MDD) values for fine-grained loess at the repository site; data from Daniel B. Stevens and Associates, Inc. (1993) and Golder Associates Inc. (1991).

Sample No.	Data Source	MDD (g cm^{-3})	Mean	S.E.
TP-121 (1)	Golder Assoc. Inc. (1991)	1.79	1.74	0.02
TP-123 (1)	Golder Assoc. Inc. (1991)	1.77		
TP-123 (5)	Golder Assoc. Inc. (1991)	1.75		
TP-124 (1)	Golder Assoc. Inc. (1991)	1.60		
TP-124 (4)	Golder Assoc. Inc. (1991)	1.77		
TP-125 (1)	Golder Assoc. Inc. (1991)	1.70		
TP-127 (4)	Golder Assoc. Inc. (1991)	1.66		
358-172	D.B. Stevens (1993)	1.73		
351-172	D.B. Stevens (1993)	1.73		
354-188	D.B. Stevens (1993)	1.88		
361-177	D.B. Stevens (1993)	1.78		

(4) Table 4. Percent rock, percent fine soil, maximum dry density, and optimum water content data the Subcontractor provided from field sampling of 0.5 in. minus product from the Common Pile (Upper Radon Barrier Material), and Type D soil stockpiled during excavation of the repository (Lower Radon Barrier Material).

Sample description	Rock (% > #4 sieve)	Fine Soil (% < #200 sieve)	Maximum Dry Density (pcf)	100% MDD (g/cm^3)	Optimum H_2O Content (%)
1/2 minus product from Common Pile	4.2	62.5	111.8	1.81	16.3
Stockpiled Type D Soil Samples					
sp#3, east, 1-6'	0.2	82.2	114.2	1.85	13.9
sp#3, east, 6-11'	0.0	78.0	115.7	1.87	14.3
sp#3, central, 1-6'	3.1	65.6	108.9	1.76	16.3
sp#3, central, 6-11'	1.4	78.4	108.8	1.76	16.6
sp#3, west, 1-6'	1.7	78.2	109.1	1.77	17.4
sp#3, west, 6-11'	0.3	78.8	110.2	1.79	16.7
mean	1.1	76.9	111.2	1.80	15.9
S.E. of the mean	0.5	2.3	1.2	0.02	0.6

(5) Target bulk density.

(6) Value is the minimum long-term tailings moisture content at the top of the tailings layer from Calc. E0269700, *Analysis of Moisture Behavior within the Repository*. Because moisture content within the tailings increases with depth, this value is conservative. The same value was used for RMM materials placed at the top of the tailings.

(7) Values are mean and standard error of the mean for all Soil Type A (loess) sampled below 120 cm in test pits on the repository site (Table 5). Use of the these values for long-term moisture content of the radon barrier is in accordance with guidance provided by the U.S. Nuclear Regulatory Commission (1989).

Table 5. In situ soil moisture in loess (Soil Type A) below a depth of 120 cm at the repository site (from Golder and Associates, Inc., 1991).

Sample Pit No.	Min. Sample Depth (cm)	Moisture Content (% dry-wt.)	$\bar{x}$	S.E.
123	213	12.5	15.8	0.6
123	156	14.2		
123	549	16.0		
124	335	15.4		
124	549	16.6		
125	183	16.8		
127	122	13.3		
106	610	18.4		
106	518	16.2		
107	152	17.4		
107	305	16.6		
107	457	18.2		
107	610	19.3		
111	152	13.8		
111	305	16.1		
113	152	11.6		
113	305	16.9		
113	762	14.1		
114	152	7.3		
115	152	19.2		
115	457	17.6		
131	610	17.0		
134	457	10.7		
134	472	19.6		
135	305	18.6		
135	457	16.1		

(8) Minimum gravimetric soil moisture content as measured in monolithic weighing lysimeters installed in native Type A loess soil at the site.

(9) Values are volume-weighted mean and standard error of the mean radium activity (pCi g^{-1}) for 3 tailings materials types (slimes, sands, mixed slimes/sands) in each of 4 tailings piles (Acid, Carbonate, East, Vanadium), and for native sediments below tailings piles with radium activity ≥ 5.0 pCi g^{-1}. The weighted mean ($\bar{x}_w$) and standard error of the mean, s($\bar{x}_w$) or S.E., were calculated using the equations (Gilbert 1987),

$$\bar{x}_w = \sum_{h=1}^{L} w_h x_h \qquad (1)$$

$$s(\bar{x}_w) = \sqrt{\sum_{h=1}^{L} \frac{w_h^2 s_h^2}{n_h}} \qquad (2)$$

In these equations, h denotes a stratum (e.g., Acid Pile sands), w_h is the volume-weighting factor for stratum h, $\bar{x}_h$ is the mean radium activity of stratum h, s^2_h is the variance of stratum h radium activity, and n_h is the number of samples from stratum h.

Table 6. Volume-weighting factors (w_h) for Sands, Sands/Slimes, Slimes, and Native Sediment

Pile	Tailings* (yd^3)	w_h Sands** (% Total)	w_h^2	w_h Sands/ Slimes** (% Total)	w_h^2	w_h Slimes** (%Total)	w_h^2
Acid	222537	0.84	0.01	3.34	0.11	7.52	0.57
Carbonate	277821	6.56	0.43	6.70	0.45	1.64	0.03
East	662122	2.84	0.08	16.69	2.79	15.98	2.55
Vanadium	66282	1.64	0.03	1.03	0.01	0.89	0.01
Native	635873	34.00	1.41				
Check	1864635	45.88		27.76		26.03	

* Tailings material quantities from Calc. E0110100

** Material percentages from Calc. E0110200

Table 7. Radium Activity ($pCi\ g^{-1}$) for Sands, Sands/Slimes, Slimes, and Native Sediment*

	Sands			Sands/ Slimes			Slimes		
Pile	$\bar{x}$	s^2	n	$\bar{x}$	s^2	n	$\bar{x}$	s^2	n
Acid	553	208986	10	1308	266504	7	1481	37438	6
Carbonate	693	146842	16	1083	280688	10	1846	2067355	6
East	499	51847	18	1163	470226	6	1462	168814	11
Vanadium	198	35948	2	914	215212	7	1240	357341	6
Native	27	1213	19						

* Data from Dames and Moore (1992) and Abramiuk et al. (1984); attached.

(10) Volume-weighted mean and S.E. of the mean values for Rn emanating fraction were calculated using equations 1 and 2 in footnote (9), volume-weighting values (w_h) from Table 6, and Rn emanation data from Dames and Moore (1992); see Calc. No. E 0269801.

Discussion:

The use of the NRC model RADON (U.S. Nuclear Regulatory Commission, 1989) has been accepted by DOE for disposal cells pursuant to UMTRCA (U.S. Department of Energy, 1989), and was also recommended by the U.S. Environmental Protection Agency for the Monticello repository design (Chem-Nuclear Geotech, Inc., 1992). RADON was used to evaluate radon flux for the following three scenarios (described in the Problem Statement of this calculation):

1. *Estimate radon flux at the top of the radon barrier, and at the surface of the repository cover, assuming a layer of residual radioactive material (RRM) will be placed last in the repository, immediately below the radon barrier. Use proctor test data for materials stockpiled or processed on site for construction of the RRM layer and radon barrier layer.*

   The RADON model calculation of the radon flux at the surface of a 60 cm radon barrier, consisting of 45 cm of stockpiled Type D soil topped with 15 cm of processed Type D material, all overlying a 90 cm RRM layer, is an order of magnitude less than the 20 pCi m^{-2} s^{-1} flux standard (Table 8). An RRM layer consisting of 90 cm of Haul Road Material produced the least radon flux, an RRM consisting of 90 cm of Interim Stockpile material produced the greatest radon flux. A RADON calculation using a 30 cm RRM layer consisting of Interim Stockpile material, and the same cover configuration, resulted in a radon flux of 4.1 pCi m^{-2} s^{-1} (Table 8), also well below the flux standard. Bulk density data for RRM, Upper Radon Barrier material, and Lower Radon Barrier material, input to the RADON runs presented in Table 8, were from recent (February 1999) Subcontractor proctor tests (Tables 2 and 4).

2. *Estimate radon flux at the top of the radon barrier, and at the surface of the repository cover, assuming no RRM layer will be placed above the tailings. Evaluate the sensitivity of radon flux to the compaction (bulk density) of the radon barrier.*

   Radon flux at the top of the radon barrier was calculated using RADON for two radon barrier compaction input values (Table 9). The first value, 1.78 g cm^{-3}, is the mean minus the standard error of the mean for proctor data the Subcontractor provided from field sampling of the Type D soil stockpiled during excavation of the repository (Table 4). The second value, 1.72 g cm^{-3}, is the mean minus the standard error of the mean for proctor analyses of fine-grained loess at in repository site footprint provided by Daniel B. Stevens and Associates, Inc. (1993) and Golder Associates Inc. (1991) prior to excavation (Table 3). The calculations suggest that radon flux is highly sensitive to compaction. Holding all other variables constant, reducing the radon barrier bulk density by 0.6 g cm^{-3} resulted in an increase in the estimate of radon flux at the top of both the radon barrier and the "sponge" layer by about a factor of 5 (Table 9). Using the 1.72 g cm^{-3} value for radon barrier bulk density, radon flux at the top of the radon barrier exceeds the 20 pCi m^{-2} s^{-1} standard, but remains below the standard at the top of the cover. Using the 1.78 g cm^{-3} value for radon barrier bulk density, radon flux at both the top of the radon barrier and at the top of the cover are is well below the standard.

3. *Estimate the maximum radium level that can be allowed in a 90 cm RRM layer without exceeding the 20 pCi m^{-2} s^{-1} flux standard at the surface of the radon barrier.*

One purpose of placing a 90 cm RRM layer above the tailings is to reduce radon emissions from the repository. Table 10 displays the results of a series of RADON runs performed to estimate the maximum radium level that could be allowed in a 90 cm RRM layer without the radon flux at the top of the radon barrier exceeding the 20 pCi m^{-2} s^{-1} standard. The more conservative radon barrier bulk density value of 1.72 g cm^{-3} from proctor data provided by Daniel B. Stevens and Associates, Inc. (1993) and Golder Associates Inc. (1991) (Table 3), was used for these runs. The results suggest that for a 90 cm RRM layer with radium levels up to 313 pCi g^{-1}, radon flux at the top of the radon barrier would not exceed the flux standard.

Table 8. RADON calculation results for evaluations of RRM placed above the tailings.

Run	Layer Configuration / Depths	Radon Flux (pCi m^{-2} s^{-1})		
		Top of Lower Rn Barrier	Top of Upper Rn Barrier	Top of Cover
1	Type E "Sponge" Soil / 132 cm Upper Radon Barrier / 15 cm Lower Radon Barrier / 45 cm RRM Haul Road Material / 90 cm	1.2	0.8	0.4
2	Type E "Sponge" Soil / 132 cm Upper Radon Barrier / 15 cm Lower Radon Barrier / 45 cm RRM RVZ / 90 cm	2.8	1.2	0.9
3	Type E "Sponge" Soil / 132 cm Upper Radon Barrier / 15 cm Lower Radon Barrier / 45 cm RRM Base of Tailings / 90 cm	2.9	2.1	1.0
4	Type E "Sponge" Soil / 132 cm Upper Radon Barrier / 15 cm Lower Radon Barrier / 45 cm RRM Interim Stockpile / 90 cm	3.3	2.3	1.1
5	Type E "Sponge" Soil / 132 cm Upper Radon Barrier / 15 cm Lower Radon Barrier / 45 cm RRM Interim Stockpile / 30 cm	5.9	4.1	1.9

Table 9. RADON calculation results for evaluations of radon flux at the top of the radon barrier, and at the surface of the repository cover, for a range of radon barrier bulk density values and assuming no RRM layer will be placed above the tailings.

Run	Layer Configuration / Depths / Bulk Density	Radon Flux ($pCi\ m^{-2}\ s^{-1}$)	
		Top of Radon Barrier	Top of Cover
6	Type E "Sponge" Soil / 132 cm Radon Barrier / 60 cm / 1.78 g cm^{-3}	6.4	3.0
7	Type E "Sponge" Soil / 132 cm Radon Barrier / 60 cm / 1.72 g cm^{-3}	33.9	16.0

Table 10. RADON calculation results for evaluations radon flux at the top of the radon barrier, and at the surface of the repository cover, for a range of radium levels in a 90-cm RRM layer placed above the tailings.

Run	Layer Configuration / Depths / Bulk Density / Ra Level	Radon Flux ($pCi\ m^{-2}\ s^{-1}$)	
		Top of Radon Barrier	Top of Cover
8	Type E "Sponge" Soil / 132 cm Radon Barrier / 60 cm / 1.72 g cm^{-3} RRM / 90 cm / 150 pCi g^{-1}	15.7	7.4
9	Type E "Sponge" Soil / 132 cm Radon Barrier / 60 cm / 1.72 g cm^{-3} RRM / 90 cm / 250 pCi g^{-1}	18.3	8.6
10	Type E "Sponge" Soil / 132 cm Radon Barrier / 60 cm / 1.72 g cm^{-3} RRM / 90 cm / 313 pCi g^{-1}	20.0	9.4
11	Type E "Sponge" Soil / 132 cm Radon Barrier / 60 cm / 1.72 g cm^{-3} RRM / 90 cm / 350 pCi g^{-1}	21.0	9.9

The following conservative assumptions in the design approach suggest that actual radon flux at the surface of the cover should be considerably less than that predicted by RADON in the above calculations.

- The radon attenuation properties of the HDPE geomembrane provide additional conservatism to the design (Ramachandran et al., 1987).
- When the repository is covered with snow or the topsoil is saturated, as typically occurs 3-4 months a year at Monticello, radon is effectively blocked from escaping into the atmosphere (U.S. Department of Energy, 1989). Snow cover and saturated topsoil were not considered in the calculation.
- The sand capillary barrier layer is excluded from the RADON flux calculation. Moisture retained in the sand layer provides an additional safety factor.

Computer Sources:

Microsoft Excel 97

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E 0110100 *Volumes of Contaminated Materials (Soils)*

E 0110200 *Distribution and Fractionation of Slimes and Sands in Tailings*

E 0268300 *Statistical Determination of Moisture-Density Relationships for Contaminated Material*

E 0269700 *Analysis of Moisture Behavior within the Repository*

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-----*****! RADON !*********-----

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RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS
ARE CALCULATED FOR MULTIPLE LAYERS

Run 1
Haul Road

CONSTANTS

RADON DECAY CONSTANT	.0000021	s^-1
RADON WATER/AIR PARTITION COEFFICIENT	.26	
SPECIFIC GRAVITY OF COVER & TAILINGS	2.65	

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS	5	
NO LIMIT ON RADON FLUX		
LAYER THICKNESS NOT OPTIMIZED		
DEFAULT SURFACE RADON CONCENTRATION	0	pCi l^-1
RADON FLUX INTO LAYER 1	0	pCi m^-2 s^-1
SURFACE FLUX PRECISION	.001	pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 Tailings

THICKNESS	1500	cm
CALCULATED POROSITY	0.434	
MEASURED MASS DENSITY	1.5	g cm^-3
MEASURED RADIUM ACTIVITY	836.9	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	21.262E-04	pCi cm^-3 s^-1
WEIGHT % MOISTURE	13.1	%
MOISTURE SATURATION FRACTION	.453	
CALCULATED DIFFUSION COEFFICIENT	14.913E-03	cm^2 s^-1

LAYER 2 Haul Road

THICKNESS	90	cm
CALCULATED POROSITY	0.317	
MEASURED MASS DENSITY	1.81	g cm^-3
MEASURED RADIUM ACTIVITY	46.4	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	19.474E-05	pCi cm^-3 s^-1
WEIGHT % MOISTURE	13.1	%
MOISTURE SATURATION FRACTION	.748	
CALCULATED DIFFUSION COEFFICIENT	18.594E-04	cm^2 s^-1

LAYER 3 Lower Radon Barrier

THICKNESS	45	cm
CALCULATED POROSITY	0.328	
MEASURED MASS DENSITY	1.78	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	00.000E-01	pCi cm^-3 s^-1
WEIGHT % MOISTURE	15.2	%
MOISTURE SATURATION FRACTION	.824	
CALCULATED DIFFUSION COEFFICIENT	80.794E-05	cm^2 s^-1

LAYER 4 Upper Radon Barrier

THICKNESS	15	cm
CALCULATED POROSITY	0.325	
MEASURED MASS DENSITY	1.79	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	00.000E-01	pCi cm^-3 s^-1
WEIGHT % MOISTURE	15.2	%
MOISTURE SATURATION FRACTION	.838	
CALCULATED DIFFUSION COEFFICIENT	66.452E-05	cm^2 s^-1

LAYER 5 Sponge Layer

THICKNESS	132	cm
CALCULATED POROSITY	0.453	
MEASURED MASS DENSITY	1.45	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	00.000E-01	pCi cm^-3 s^-1
WEIGHT % MOISTURE	12.4	%
MOISTURE SATURATION FRACTION	.397	
CALCULATED DIFFUSION COEFFICIENT	19.038E-03	cm^2 s^-1

DATA SENT TO THE FILE 'RNDATA' ON DRIVE A:

N	F01	CN1	ICOST	CRITJ	ACC
5	00.000E-01	00.000E-01	0	00.000E-01	10.000E-04

LAYER	DX	D	P	Q	XMS	RHO
1	15.000E+02	14.913E-03	43.396E-02	21.262E-04	45.280E-02	1.500
2	90.000E+00	18.594E-04	31.698E-02	19.474E-05	74.803E-02	1.810
3	45.000E+00	80.794E-05	32.830E-02	00.000E-01	82.412E-02	1.780
4	15.000E+00	66.452E-05	32.453E-02	00.000E-01	83.839E-02	1.790
5	13.200E+01	19.038E-03	45.283E-02	00.000E-01	39.706E-02	1.450

BARE SOURCE FLUX FROM LAYER 1: 77.754E+01 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	15.000E+02	99.586E+00	88.277E+04
2	90.000E+00	10.482E+00	88.525E+03
3	45.000E+00	11.572E-01	70.600E+02
4	15.000E+00	80.518E-02	42.178E+01
5	13.200E+01	37.889E-02	00.000E-01

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RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS
ARE CALCULATED FOR MULTIPLE LAYERS

Run 2
RVZ

CONSTANTS

RADON DECAY CONSTANT	.0000021	s^-1
RADON WATER/AIR PARTITION COEFFICIENT	.26	
SPECIFIC GRAVITY OF COVER & TAILINGS	2.65	

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS	5	
NO LIMIT ON RADON FLUX		
LAYER THICKNESS NOT OPTIMIZED		
DEFAULT SURFACE RADON CONCENTRATION	0	pCi l^-1
RADON FLUX INTO LAYER 1	0	pCi m^-2 s^-1
SURFACE FLUX PRECISION	.001	pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 Tailings

THICKNESS	1500	cm
CALCULATED POROSITY	0.434	
MEASURED MASS DENSITY	1.5	g cm^-3
MEASURED RADIUM ACTIVITY	836.9	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	21.262E-04	pCi cm^-3 s^-1
WEIGHT % MOISTURE	13.1	%
MOISTURE SATURATION FRACTION	.453	
CALCULATED DIFFUSION COEFFICIENT	14.913E-03	cm^2 s^-1

LAYER 2 RVZ

THICKNESS	90	cm
CALCULATED POROSITY	0.434	
MEASURED MASS DENSITY	1.5	g cm^-3
MEASURED RADIUM ACTIVITY	6.8	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	17.276E-06	pCi cm^-3 s^-1
WEIGHT % MOISTURE	13.1	%
MOISTURE SATURATION FRACTION	.453	
CALCULATED DIFFUSION COEFFICIENT	14.913E-03	cm^2 s^-1

LAYER 3 Lower Radon Barrier

THICKNESS	45	cm
CALCULATED POROSITY	0.328	
MEASURED MASS DENSITY	1.78	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	00.000E-01	pCi cm^-3 s^-1
WEIGHT % MOISTURE	15.2	%
MOISTURE SATURATION FRACTION	.824	
CALCULATED DIFFUSION COEFFICIENT	80.794E-05	cm^2 s^-1

LAYER 4 Upper Radon Barrier

THICKNESS	15	cm
CALCULATED POROSITY	0.325	
MEASURED MASS DENSITY	1.79	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	00.000E-01	pCi cm^-3 s^-1
WEIGHT % MOISTURE	15.2	%
MOISTURE SATURATION FRACTION	.838	
CALCULATED DIFFUSION COEFFICIENT	66.452E-05	cm^2 s^-1

LAYER 5 Sponge Layer

THICKNESS	132	cm
CALCULATED POROSITY	0.453	
MEASURED MASS DENSITY	1.45	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	00.000E-01	pCi cm^-3 s^-1
WEIGHT % MOISTURE	12.4	%
MOISTURE SATURATION FRACTION	.397	
CALCULATED DIFFUSION COEFFICIENT	19.038E-03	cm^2 s^-1

DATA SENT TO THE FILE 'RNDATA' ON DRIVE A:

N	F01	CN1	ICOST	CRITJ	ACC
5	00.000E-01	00.000E-01	0	00.000E-01	10.000E-04

LAYER	DX	D	P	Q	XMS	RHO
1	15.000E+02	14.913E-03	43.396E-02	21.262E-04	45.280E-02	1.500
2	90.000E+00	14.913E-03	43.396E-02	17.276E-06	45.280E-02	1.500
3	45.000E+00	80.794E-05	32.830E-02	00.000E-01	82.412E-02	1.780
4	15.000E+00	66.452E-05	32.453E-02	00.000E-01	83.839E-02	1.790
5	13.200E+01	19.038E-03	45.283E-02	00.000E-01	39.706E-02	1.450

BARE SOURCE FLUX FROM LAYER 1: 77.754E+01 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	15.000E+02	34.878E+01	55.822E+04
2	90.000E+00	25.457E+00	32.020E+04
3	45.000E+00	28.105E-01	17.146E+03
4	15.000E+00	19.555E-01	10.244E+02
5	13.200E+01	92.020E-02	00.000E-01

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RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS
ARE CALCULATED FOR MULTIPLE LAYERS

Run 3
Base of Tailings

CONSTANTS

RADON DECAY CONSTANT	.0000021	s^-1
RADON WATER/AIR PARTITION COEFFICIENT	.26	
SPECIFIC GRAVITY OF COVER & TAILINGS	2.65	

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS	5	
NO LIMIT ON RADON FLUX		
LAYER THICKNESS NOT OPTIMIZED		
DEFAULT SURFACE RADON CONCENTRATION	0	pCi l^-1
RADON FLUX INTO LAYER 1	0	pCi m^-2 s^-1
SURFACE FLUX PRECISION	.001	pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 Tailings

THICKNESS	1500	cm
CALCULATED POROSITY	0.434	
MEASURED MASS DENSITY	1.5	g cm^-3
MEASURED RADIUM ACTIVITY	836.9	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	21.262E-04	pCi cm^-3 s^-1
WEIGHT % MOISTURE	13.1	%
MOISTURE SATURATION FRACTION	.453	
CALCULATED DIFFUSION COEFFICIENT	14.913E-03	cm^2 s^-1

LAYER 2 Base of Tailings

THICKNESS	90	cm
CALCULATED POROSITY	0.385	
MEASURED MASS DENSITY	1.63	g cm^-3
MEASURED RADIUM ACTIVITY	79.59999999999999	
pCi g^-1		
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	24.776E-05	pCi cm^-3 s^-1
WEIGHT % MOISTURE	13.1	%
MOISTURE SATURATION FRACTION	.555	
CALCULATED DIFFUSION COEFFICIENT	85.680E-04	cm^2 s^-1

LAYER 3 Lower Radon Barrier

THICKNESS	45	cm
CALCULATED POROSITY	0.328	
MEASURED MASS DENSITY	1.78	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	00.000E-01	pCi cm^-3 s^-1
WEIGHT % MOISTURE	15.2	%
MOISTURE SATURATION FRACTION	.824	
CALCULATED DIFFUSION COEFFICIENT	80.794E-05	cm^2 s^-1

LAYER 4 Upper Radon Barrier

THICKNESS	15	cm
CALCULATED POROSITY	0.325	
MEASURED MASS DENSITY	1.79	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	00.000E-01	pCi cm^-3 s^-1
WEIGHT % MOISTURE	15.2	%
MOISTURE SATURATION FRACTION	.838	
CALCULATED DIFFUSION COEFFICIENT	66.452E-05	cm^2 s^-1

LAYER 5 Sponge Layer

THICKNESS	132	cm
CALCULATED POROSITY	0.453	
MEASURED MASS DENSITY	1.45	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	00.000E-01	pCi cm^-3 s^-1
WEIGHT % MOISTURE	12.4	%
MOISTURE SATURATION FRACTION	.397	
CALCULATED DIFFUSION COEFFICIENT	19.038E-03	cm^2 s^-1

DATA SENT TO THE FILE 'RNDATA' ON DRIVE A:

N	F01	CN1	ICOST	CRITJ	ACC
5	00.000E-01	00.000E-01	0	00.000E-01	10.000E-04

LAYER	DX	D	P	Q	XMS	RHO
1	15.000E+02	14.913E-03	43.396E-02	21.262E-04	45.280E-02	1.500
2	90.000E+00	85.680E-04	38.491E-02	24.776E-05	55.476E-02	1.630
3	45.000E+00	80.794E-05	32.830E-02	00.000E-01	82.412E-02	1.780
4	15.000E+00	66.452E-05	32.453E-02	00.000E-01	83.839E-02	1.790
5	13.200E+01	19.038E-03	45.283E-02	00.000E-01	39.706E-02	1.450

BARE SOURCE FLUX FROM LAYER 1: 77.754E+01 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	15.000E+02	24.176E+01	69.759E+04
2	90.000E+00	27.103E+00	30.223E+04
3	45.000E+00	29.923E-01	18.255E+03
4	15.000E+00	20.820E-01	10.906E+02
5	13.200E+01	97.972E-02	00.000E-01

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RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS ARE CALCULATED FOR MULTIPLE LAYERS

Run 4

Interim Stockpile

CONSTANTS

RADON DECAY CONSTANT	.0000021	s^-1
RADON WATER/AIR PARTITION COEFFICIENT	.26	
SPECIFIC GRAVITY OF COVER & TAILINGS	2.65	

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS	5	
NO LIMIT ON RADON FLUX		
LAYER THICKNESS NOT OPTIMIZED		
DEFAULT SURFACE RADON CONCENTRATION	0	pCi l^-1
RADON FLUX INTO LAYER 1	0	pCi m^-2 s^-1
SURFACE FLUX PRECISION	.001	pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 Tailings

THICKNESS	1500	cm
CALCULATED POROSITY	0.434	
MEASURED MASS DENSITY	1.5	g cm^-3
MEASURED RADIUM ACTIVITY	836.9	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	21.262E-04	pCi cm^-3 s^-1
WEIGHT % MOISTURE	13.1	%
MOISTURE SATURATION FRACTION	.453	
CALCULATED DIFFUSION COEFFICIENT	14.913E-03	cm^2 s^-1

LAYER 2 Interim Stockpile

THICKNESS	90	cm
CALCULATED POROSITY	0.430	
MEASURED MASS DENSITY	1.51	g cm^-3
MEASURED RADIUM ACTIVITY	90.7	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	23.400E-05	pCi cm^-3 s^-1
WEIGHT % MOISTURE	13.1	%
MOISTURE SATURATION FRACTION	.460	
CALCULATED DIFFUSION COEFFICIENT	14.402E-03	cm^2 s^-1

LAYER 3 Lower Radon Barrier

THICKNESS	45	cm
CALCULATED POROSITY	0.328	
MEASURED MASS DENSITY	1.78	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	00.000E-01	pCi cm^-3 s^-1
WEIGHT % MOISTURE	15.2	%
MOISTURE SATURATION FRACTION	.824	
CALCULATED DIFFUSION COEFFICIENT	80.794E-05	cm^2 s^-1

LAYER 4 Upper Radon Barrier

THICKNESS	15	cm
CALCULATED POROSITY	0.325	
MEASURED MASS DENSITY	1.79	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	00.000E-01	pCi cm^-3 s^-1
WEIGHT % MOISTURE	15.2	%
MOISTURE SATURATION FRACTION	.838	
CALCULATED DIFFUSION COEFFICIENT	66.452E-05	cm^2 s^-1

LAYER 5 Sponge Layer

THICKNESS	132	cm
CALCULATED POROSITY	0.453	
MEASURED MASS DENSITY	1.45	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	00.000E-01	pCi cm^-3 s^-1
WEIGHT % MOISTURE	12.4	%
MOISTURE SATURATION FRACTION	.397	
CALCULATED DIFFUSION COEFFICIENT	19.038E-03	cm^2 s^-1

DATA SENT TO THE FILE 'RNDATA' ON DRIVE A:

N	F01	CN1	ICOST	CRITJ	ACC
5	00.000E-01	00.000E-01	0	00.000E-01	10.000E-04

LAYER	DX	D	P	Q	XMS	RHO
1	15.000E+02	14.913E-03	43.396E-02	21.262E-04	45.280E-02	1.500
2	90.000E+00	14.402E-03	43.019E-02	23.400E-05	45.982E-02	1.510
3	45.000E+00	80.794E-05	32.830E-02	00.000E-01	82.412E-02	1.780
4	15.000E+00	66.452E-05	32.453E-02	00.000E-01	83.839E-02	1.790
5	13.200E+01	19.038E-03	45.283E-02	00.000E-01	39.706E-02	1.450

BARE SOURCE FLUX FROM LAYER 1: 77.754E+01 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	15.000E+02	31.085E+01	60.762E+04
2	90.000E+00	30.206E+00	37.697E+04
3	45.000E+00	33.348E-01	20.345E+03
4	15.000E+00	23.203E-01	12.154E+02
5	13.200E+01	10.919E-01	00.000E-01

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RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS
ARE CALCULATED FOR MULTIPLE LAYERS

Run 5

30 cm Interim Stockpile

CONSTANTS

RADON DECAY CONSTANT	.0000021	s^-1
RADON WATER/AIR PARTITION COEFFICIENT	.26	
SPECIFIC GRAVITY OF COVER & TAILINGS	2.65	

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS	5	
NO LIMIT ON RADON FLUX		
LAYER THICKNESS NOT OPTIMIZED		
DEFAULT SURFACE RADON CONCENTRATION	0	pCi l^-1
RADON FLUX INTO LAYER 1	0	pCi m^-2 s^-1
SURFACE FLUX PRECISION	.001	pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 Tailings

THICKNESS	1500	cm
CALCULATED POROSITY	0.434	
MEASURED MASS DENSITY	1.5	g cm^-3
MEASURED RADIUM ACTIVITY	836.9	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	21.262E-04	pCi cm^-3 s^-1
WEIGHT % MOISTURE	13.1	%
MOISTURE SATURATION FRACTION	.453	
CALCULATED DIFFUSION COEFFICIENT	14.913E-03	cm^2 s^-1

LAYER 2 Interim Stockpile

THICKNESS	30	cm
CALCULATED POROSITY	0.430	
MEASURED MASS DENSITY	1.51	g cm^-3
MEASURED RADIUM ACTIVITY	90.7	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	23.400E-05	pCi cm^-3 s^-1
WEIGHT % MOISTURE	13	%
MOISTURE SATURATION FRACTION	.456	
CALCULATED DIFFUSION COEFFICIENT	14.613E-03	cm^2 s^-1

LAYER 3 Lower Radon Barrier

THICKNESS	45	cm
CALCULATED POROSITY	0.328	
MEASURED MASS DENSITY	1.78	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	00.000E-01	pCi cm^-3 s^-1
WEIGHT % MOISTURE	15.2	%
MOISTURE SATURATION FRACTION	.824	
CALCULATED DIFFUSION COEFFICIENT	80.794E-05	cm^2 s^-1

LAYER 4 Upper Radon Barrier

THICKNESS	15	cm
CALCULATED POROSITY	0.325	
MEASURED MASS DENSITY	1.79	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	00.000E-01	pCi cm^-3 s^-1
WEIGHT % MOISTURE	15.2	%
MOISTURE SATURATION FRACTION	.838	
CALCULATED DIFFUSION COEFFICIENT	66.452E-05	cm^2 s^-1

LAYER 5 Sponge Layer

THICKNESS	132	cm
CALCULATED POROSITY	0.453	
MEASURED MASS DENSITY	1.45	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	00.000E-01	pCi cm^-3 s^-1
WEIGHT % MOISTURE	12.4	%
MOISTURE SATURATION FRACTION	.397	
CALCULATED DIFFUSION COEFFICIENT	19.038E-03	cm^2 s^-1

DATA SENT TO THE FILE 'RNDATA' ON DRIVE A:

N	F01	CN1	ICOST	CRITJ	ACC
5	00.000E-01	00.000E-01	0	00.000E-01	10.000E-04

LAYER	DX	D	P	Q	XMS	RHO
1	15.000E+02	14.913E-03	43.396E-02	21.262E-04	45.280E-02	1.500
2	30.000E+00	14.613E-03	43.019E-02	23.400E-05	45.631E-02	1.510
3	45.000E+00	80.794E-05	32.830E-02	00.000E-01	82.412E-02	1.780
4	15.000E+00	66.452E-05	32.453E-02	00.000E-01	83.839E-02	1.790
5	13.200E+01	19.038E-03	45.283E-02	00.000E-01	39.706E-02	1.450

BARE SOURCE FLUX FROM LAYER 1: 77.754E+01 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	15.000E+02	21.195E+01	73.642E+04
2	30.000E+00	53.545E+00	67.087E+04
3	45.000E+00	59.114E-01	36.065E+03
4	15.000E+00	41.131E-01	21.546E+02
5	13.200E+01	19.355E-01	00.000E-01

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RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS
ARE CALCULATED FOR MULTIPLE LAYERS

Run 6
No RRM

CONSTANTS

RADON DECAY CONSTANT	.0000021	s^-1
RADON WATER/AIR PARTITION COEFFICIENT	.26	
SPECIFIC GRAVITY OF COVER & TAILINGS	2.65	

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS	3	
NO LIMIT ON RADON FLUX		
LAYER THICKNESS NOT OPTIMIZED		
DEFAULT SURFACE RADON CONCENTRATION	0	pCi l^-1
RADON FLUX INTO LAYER 1	0	pCi m^-2 s^-1
SURFACE FLUX PRECISION	.001	pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 Tailings

THICKNESS	1500	cm
CALCULATED POROSITY	0.434	
MEASURED MASS DENSITY	1.5	g cm^-3
MEASURED RADIUM ACTIVITY	836.9	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	21.262E-04	pCi cm^-3 s^-1
WEIGHT % MOISTURE	13.1	%
MOISTURE SATURATION FRACTION	.453	
CALCULATED DIFFUSION COEFFICIENT	14.913E-03	cm^2 s^-1

LAYER 2 Radon Barrier

THICKNESS	60	cm
CALCULATED POROSITY	0.328	
MEASURED MASS DENSITY	1.78	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	00.000E-01	pCi cm^-3 s^-1
WEIGHT % MOISTURE	15.2	%
MOISTURE SATURATION FRACTION	.824	
CALCULATED DIFFUSION COEFFICIENT	80.794E-05	cm^2 s^-1

LAYER 3 Sponge

THICKNESS	132	cm
CALCULATED POROSITY	0.453	
MEASURED MASS DENSITY	1.45	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	00.000E-01	pCi cm^-3 s^-1
WEIGHT % MOISTURE	12.4	%
MOISTURE SATURATION FRACTION	.397	
CALCULATED DIFFUSION COEFFICIENT	19.038E-03	cm^2 s^-1

DATA SENT TO THE FILE 'RNDATA' ON DRIVE A:

N	F01	CN1	ICOST	CRITJ	ACC
3	00.000E-01	00.000E-01	0	00.000E-01	10.000E-04

LAYER	DX	D	P	Q	XMS	RHO
1	15.000E+02	14.913E-03	43.396E-02	21.262E-04	45.280E-02	1.500
2	60.000E+00	80.794E-05	32.830E-02	00.000E-01	82.412E-02	1.780
3	13.200E+01	19.038E-03	45.283E-02	00.000E-01	39.706E-02	1.450

BARE SOURCE FLUX FROM LAYER 1: 77.754E+01 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	15.000E+02	73.064E+00	91.731E+04
2	60.000E+00	63.812E-01	34.356E+02
3	13.200E+01	30.028E-01	00.000E-01

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RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS ARE CALCULATED FOR MULTIPLE LAYERS

Run 7
No RRM

CONSTANTS

RADON DECAY CONSTANT	.0000021	s^-1
RADON WATER/AIR PARTITION COEFFICIENT	.26	
SPECIFIC GRAVITY OF COVER & TAILINGS	2.65	

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS	3	
NO LIMIT ON RADON FLUX		
LAYER THICKNESS NOT OPTIMIZED		
DEFAULT SURFACE RADON CONCENTRATION	0	pCi l^-1
RADON FLUX INTO LAYER 1	0	pCi m^-2 s^-1
SURFACE FLUX PRECISION	.001	pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 Tailings

THICKNESS	1500	cm
CALCULATED POROSITY	0.434	
MEASURED MASS DENSITY	1.5	g cm^-3
MEASURED RADIUM ACTIVITY	836.9	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	21.262E-04	pCi cm^-3 s^-1
WEIGHT % MOISTURE	13.1	%
MOISTURE SATURATION FRACTION	.453	
CALCULATED DIFFUSION COEFFICIENT	14.913E-03	cm^2 s^-1

LAYER 2 Radon Barrier

THICKNESS	60	cm
CALCULATED POROSITY	0.351	
MEASURED MASS DENSITY	1.72	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	00.000E-01	pCi cm^-3 s^-1
WEIGHT % MOISTURE	15.2	%
MOISTURE SATURATION FRACTION	.745	
CALCULATED DIFFUSION COEFFICIENT	20.501E-04	cm^2 s^-1

LAYER 3 Sponge

THICKNESS	132	cm
CALCULATED POROSITY	0.453	
MEASURED MASS DENSITY	1.45	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	00.000E-01	pCi cm^-3 s^-1
WEIGHT % MOISTURE	12.4	%
MOISTURE SATURATION FRACTION	.397	
CALCULATED DIFFUSION COEFFICIENT	19.038E-03	cm^2 s^-1

DATA SENT TO THE FILE 'RNDATA' ON DRIVE A:

N	F01	CN1	ICOST	CRITJ	ACC
3	00.000E-01	00.000E-01	0	00.000E-01	10.000E-04

LAYER	DX	D	P	Q	XMS	RHO
1	15.000E+02	14.913E-03	43.396E-02	21.262E-04	45.280E-02	1.500
2	60.000E+00	20.501E-04	35.094E-02	00.000E-01	74.496E-02	1.720
3	13.200E+01	19.038E-03	45.283E-02	00.000E-01	39.706E-02	1.450

BARE SOURCE FLUX FROM LAYER 1: 77.754E+01 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	15.000E+02	13.440E+01	83.743E+04
2	60.000E+00	33.931E+00	21.011E+03
3	13.200E+01	15.967E+00	00.000E-01

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RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS
ARE CALCULATED FOR MULTIPLE LAYERS

Run 8
PPMRadium150

CONSTANTS

RADON DECAY CONSTANT	.0000021	s^-1
RADON WATER/AIR PARTITION COEFFICIENT	.26	
SPECIFIC GRAVITY OF COVER & TAILINGS	2.65	

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS	4	
NO LIMIT ON RADON FLUX		
LAYER THICKNESS NOT OPTIMIZED		
DEFAULT SURFACE RADON CONCENTRATION	0	pCi l^-1
RADON FLUX INTO LAYER 1	0	pCi m^-2 s^-1
SURFACE FLUX PRECISION	.001	pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 Tailings

THICKNESS	1500	cm
CALCULATED POROSITY	0.434	
MEASURED MASS DENSITY	1.5	g cm^-3
MEASURED RADIUM ACTIVITY	836.9	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	21.262E-04	pCi cm^-3 s^-1
WEIGHT % MOISTURE	13.1	%
MOISTURE SATURATION FRACTION	.453	
CALCULATED DIFFUSION COEFFICIENT	14.913E-03	cm^2 s^-1

LAYER 2 PPM150

THICKNESS	90	cm
CALCULATED POROSITY	0.434	
MEASURED MASS DENSITY	1.5	g cm^-3
MEASURED RADIUM ACTIVITY	150	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	38.108E-05	pCi cm^-3 s^-1
WEIGHT % MOISTURE	13.1	%
MOISTURE SATURATION FRACTION	.453	
CALCULATED DIFFUSION COEFFICIENT	14.913E-03	cm^2 s^-1

LAYER 3 Radon Barrier

THICKNESS	60	cm
CALCULATED POROSITY	0.351	
MEASURED MASS DENSITY	1.72	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	00.000E-01	pCi cm^-3 s^-1
WEIGHT % MOISTURE	15.2	%
MOISTURE SATURATION FRACTION	.745	
CALCULATED DIFFUSION COEFFICIENT	20.501E-04	cm^2 s^-1

LAYER 4 Sponge

THICKNESS	132	cm
CALCULATED POROSITY	0.453	
MEASURED MASS DENSITY	1.45	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	00.000E-01	pCi cm^-3 s^-1
WEIGHT % MOISTURE	12.4	%
MOISTURE SATURATION FRACTION	.397	
CALCULATED DIFFUSION COEFFICIENT	19.038E-03	cm^2 s^-1

DATA SENT TO THE FILE 'RNDATA' ON DRIVE A:

N	F01	CN1	ICOST	CRITJ	ACC
4	00.000E-01	00.000E-01	0	00.000E-01	10.000E-04

LAYER	DX	D	P	Q	XMS	RHO
1	15.000E+02	14.913E-03	43.396E-02	21.262E-04	45.280E-02	1.500
2	90.000E+00	14.913E-03	43.396E-02	38.108E-05	45.280E-02	1.500
3	60.000E+00	20.501E-04	35.094E-02	00.000E-01	74.496E-02	1.720
4	13.200E+01	19.038E-03	45.283E-02	00.000E-01	39.706E-02	1.450

BARE SOURCE FLUX FROM LAYER 1: 77.754E+01 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	15.000E+02	30.268E+01	61.826E+04
2	90.000E+00	62.000E+00	38.632E+04
3	60.000E+00	15.653E+00	96.928E+02
4	13.200E+01	73.658E-01	00.000E-01

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RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS
ARE CALCULATED FOR MULTIPLE LAYERS

Run 9
PPMRadium250

CONSTANTS

RADON DECAY CONSTANT	.0000021	s^-1
RADON WATER/AIR PARTITION COEFFICIENT	.26	
SPECIFIC GRAVITY OF COVER & TAILINGS	2.65	

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS	4	
NO LIMIT ON RADON FLUX		
LAYER THICKNESS NOT OPTIMIZED		
DEFAULT SURFACE RADON CONCENTRATION	0	pCi l^-1
RADON FLUX INTO LAYER 1	0	pCi m^-2 s^-1
SURFACE FLUX PRECISION	.001	pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 Tailings

THICKNESS	1500	cm
CALCULATED POROSITY	0.434	
MEASURED MASS DENSITY	1.5	g cm^-3
MEASURED RADIUM ACTIVITY	836.9	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	21.262E-04	pCi cm^-3 s^-1
WEIGHT % MOISTURE	13.1	%
MOISTURE SATURATION FRACTION	.453	
CALCULATED DIFFUSION COEFFICIENT	14.913E-03	cm^2 s^-1

LAYER 2 PPM250

THICKNESS	90	cm
CALCULATED POROSITY	0.434	
MEASURED MASS DENSITY	1.5	g cm^-3
MEASURED RADIUM ACTIVITY	250	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	63.514E-05	pCi cm^-3 s^-1
WEIGHT % MOISTURE	13.1	%
MOISTURE SATURATION FRACTION	.453	
CALCULATED DIFFUSION COEFFICIENT	14.913E-03	cm^2 s^-1

LAYER 3 Radon Barrier

THICKNESS	60	cm
CALCULATED POROSITY	0.351	
MEASURED MASS DENSITY	1.72	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	00.000E-01	pCi cm^-3 s^-1
WEIGHT % MOISTURE	15.2	%
MOISTURE SATURATION FRACTION	.745	
CALCULATED DIFFUSION COEFFICIENT	20.501E-04	cm^2 s^-1

LAYER 4 Sponge

THICKNESS	132	cm
CALCULATED POROSITY	0.453	
MEASURED MASS DENSITY	1.45	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	00.000E-01	pCi cm^-3 s^-1
WEIGHT % MOISTURE	12.4	%
MOISTURE SATURATION FRACTION	.397	
CALCULATED DIFFUSION COEFFICIENT	19.038E-03	cm^2 s^-1

DATA SENT TO THE FILE 'RNDATA' ON DRIVE A:

N	F01	CN1	ICOST	CRITJ	ACC
4	00.000E-01	00.000E-01	0	00.000E-01	10.000E-04

LAYER	DX	D	P	Q	XMS	RHO
1	15.000E+02	14.913E-03	43.396E-02	21.262E-04	45.280E-02	1.500
2	90.000E+00	14.913E-03	43.396E-02	63.514E-05	45.280E-02	1.500
3	60.000E+00	20.501E-04	35.094E-02	00.000E-01	74.496E-02	1.720
4	13.200E+01	19.038E-03	45.283E-02	00.000E-01	39.706E-02	1.450

BARE SOURCE FLUX FROM LAYER 1: 77.754E+01 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	15.000E+02	26.534E+01	66.689E+04
2	90.000E+00	72.540E+00	45.200E+04
3	60.000E+00	18.314E+00	11.341E+03
4	13.200E+01	86.180E-01	00.000E-01

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RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS
ARE CALCULATED FOR MULTIPLE LAYERS

Run 10

PPMRadium313

CONSTANTS

RADON DECAY CONSTANT	.0000021	s^-1
RADON WATER/AIR PARTITION COEFFICIENT	.26	
SPECIFIC GRAVITY OF COVER & TAILINGS	2.65	

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS	4	
NO LIMIT ON RADON FLUX		
LAYER THICKNESS NOT OPTIMIZED		
DEFAULT SURFACE RADON CONCENTRATION	0	pCi l^-1
RADON FLUX INTO LAYER 1	0	pCi m^-2 s^-1
SURFACE FLUX PRECISION	.001	pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 Tailings

THICKNESS	1500	cm
CALCULATED POROSITY	0.434	
MEASURED MASS DENSITY	1.5	g cm^-3
MEASURED RADIUM ACTIVITY	836.9	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	21.262E-04	pCi cm^-3 s^-1
WEIGHT % MOISTURE	13.1	%
MOISTURE SATURATION FRACTION	.453	
CALCULATED DIFFUSION COEFFICIENT	14.913E-03	cm^2 s^-1

LAYER 2 PPM313

THICKNESS	90	cm
CALCULATED POROSITY	0.434	
MEASURED MASS DENSITY	1.5	g cm^-3
MEASURED RADIUM ACTIVITY	313	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	79.519E-05	pCi cm^-3 s^-1
WEIGHT % MOISTURE	13.1	%
MOISTURE SATURATION FRACTION	.453	
CALCULATED DIFFUSION COEFFICIENT	14.913E-03	cm^2 s^-1

LAYER 3 Radon Barrier

THICKNESS	60	cm
CALCULATED POROSITY	0.351	
MEASURED MASS DENSITY	1.72	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	00.000E-01	pCi cm^-3 s^-1
WEIGHT % MOISTURE	15.2	%
MOISTURE SATURATION FRACTION	.745	
CALCULATED DIFFUSION COEFFICIENT	20.501E-04	cm^2 s^-1

LAYER 4 Sponge

THICKNESS	132	cm
CALCULATED POROSITY	0.453	
MEASURED MASS DENSITY	1.45	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	00.000E-01	pCi cm^-3 s^-1
WEIGHT % MOISTURE	12.4	%
MOISTURE SATURATION FRACTION	.397	
CALCULATED DIFFUSION COEFFICIENT	19.038E-03	cm^2 s^-1

DATA SENT TO THE FILE 'RNDATA' ON DRIVE A:

N	F01	CN1	ICOST	CRITJ	ACC
4	00.000E-01	00.000E-01	0	00.000E-01	10.000E-04

LAYER	DX	D	P	Q	XMS	RHO
1	15.000E+02	14.913E-03	43.396E-02	21.262E-04	45.280E-02	1.500
2	90.000E+00	14.913E-03	43.396E-02	79.519E-05	45.280E-02	1.500
3	60.000E+00	20.501E-04	35.094E-02	00.000E-01	74.496E-02	1.720
4	13.200E+01	19.038E-03	45.283E-02	00.000E-01	39.706E-02	1.450

BARE SOURCE FLUX FROM LAYER 1: 77.754E+01 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	15.000E+02	24.182E+01	69.753E+04
2	90.000E+00	79.180E+00	49.337E+04
3	60.000E+00	19.990E+00	12.379E+03
4	13.200E+01	94.070E-01	00.000E-01

-----*****! RADON !*****-----

Version 1.2 - May 22, 1989 - G.F. birchard tel.# (301)492-7000
U.S. Nuclear Regulatory Commission Office of Research

RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS
ARE CALCULATED FOR MULTIPLE LAYERS

Run 11

PPMRadium350

CONSTANTS

RADON DECAY CONSTANT	.0000021	s^-1
RADON WATER/AIR PARTITION COEFFICIENT	.26	
SPECIFIC GRAVITY OF COVER & TAILINGS	2.65	

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS	4	
NO LIMIT ON RADON FLUX		
LAYER THICKNESS NOT OPTIMIZED		
DEFAULT SURFACE RADON CONCENTRATION	0	pCi l^-1
RADON FLUX INTO LAYER 1	0	pCi m^-2 s^-1
SURFACE FLUX PRECISION	.001	pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 Tailings

THICKNESS	1500	cm
CALCULATED POROSITY	0.434	
MEASURED MASS DENSITY	1.5	g cm^-3
MEASURED RADIUM ACTIVITY	836.9	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	21.262E-04	pCi cm^-3 s^-1
WEIGHT % MOISTURE	13.1	%
MOISTURE SATURATION FRACTION	.453	
CALCULATED DIFFUSION COEFFICIENT	14.913E-03	cm^2 s^-1

LAYER 2 PPM350

THICKNESS	90	cm
CALCULATED POROSITY	0.434	
MEASURED MASS DENSITY	1.5	g cm^-3
MEASURED RADIUM ACTIVITY	350	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	88.919E-05	pCi cm^-3 s^-1
WEIGHT % MOISTURE	13.1	%
MOISTURE SATURATION FRACTION	.453	
CALCULATED DIFFUSION COEFFICIENT	14.913E-03	cm^2 s^-1

LAYER 3 Radon Barrier

THICKNESS	60	cm
CALCULATED POROSITY	0.351	
MEASURED MASS DENSITY	1.72	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	00.000E-01	pCi cm^-3 s^-1
WEIGHT % MOISTURE	15.2	%
MOISTURE SATURATION FRACTION	.745	
CALCULATED DIFFUSION COEFFICIENT	20.501E-04	cm^2 s^-1

LAYER 4 Sponge

THICKNESS	132	cm
CALCULATED POROSITY	0.453	
MEASURED MASS DENSITY	1.45	g cm^-3
MEASURED RADIUM ACTIVITY	0	pCi g^-1
MEASURED EMANATION COEFFICIENT	.35	
CALCULATED SOURCE TERM CONCENTRATION	00.000E-01	pCi cm^-3 s^-1
WEIGHT % MOISTURE	12.4	%
MOISTURE SATURATION FRACTION	.397	
CALCULATED DIFFUSION COEFFICIENT	19.038E-03	cm^2 s^-1

DATA SENT TO THE FILE 'RNDATA' ON DRIVE A:

N	F01	CN1	ICOST	CRITJ	ACC
4	00.000E-01	00.000E-01	0	00.000E-01	10.000E-04

LAYER	DX	D	P	Q	XMS	RHO
1	15.000E+02	14.913E-03	43.396E-02	21.262E-04	45.280E-02	1.500
2	90.000E+00	14.913E-03	43.396E-02	88.919E-05	45.280E-02	1.500
3	60.000E+00	20.501E-04	35.094E-02	00.000E-01	74.496E-02	1.720
4	13.200E+01	19.038E-03	45.283E-02	00.000E-01	39.706E-02	1.450

BARE SOURCE FLUX FROM LAYER 1: 77.754E+01 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	15.000E+02	22.800E+01	71.552E+04
2	90.000E+00	83.080E+00	51.767E+04
3	60.000E+00	20.975E+00	12.988E+03
4	13.200E+01	98.703E-01	00.000E-01